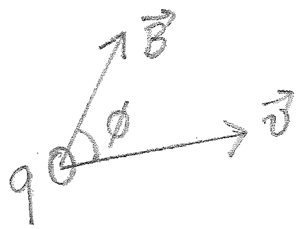
Introduction to Magnetic Fields

Magnetic fields can exert forces on moving charges in much the same way that electric fields exert forces on charges. There are some notable differences, however. The force exerted on a charge by the electric field is proportional to the charge and the electric field, and is independent of the velocity of that charge ($\vec{F} = q\vec{E}$). In particular, the electric field exerts forces on stationary as well as moving charges. On the other hand, magnetic fields only exert forces on moving charges, and that force is proportional to the velocity of the charge, as well as the charge itself and the magnetic field. Furthermore, the direction of the magnetic force is not the same as the magnetic field, but rather is perpendicular to it. The force law is given by

$$\vec{F} = q(\vec{v} \times \vec{B}),$$

where q is the charge, $\vec{v}$ is its velocity, and $\vec{B}$ is the magnetic field. You should review the cross product in Chapter 3 of your textbook.



The magnitude of this force is given by

$$F = |q|vB\sin\phi,$$

where ϕ is the angle between $\vec{v}$ and $\vec{B}$ (recall that the magnitude of $\vec{v} \times \vec{B}$ itself is $vB\sin\phi$). The direction of the force is given by the right-hand rule, as follows:

1. First, use the right-hand rule for cross products to determine the direction of $\vec{v} \times \vec{B}$. In the example drawn above, $\vec{v} \times \vec{B}$ points out of the page.

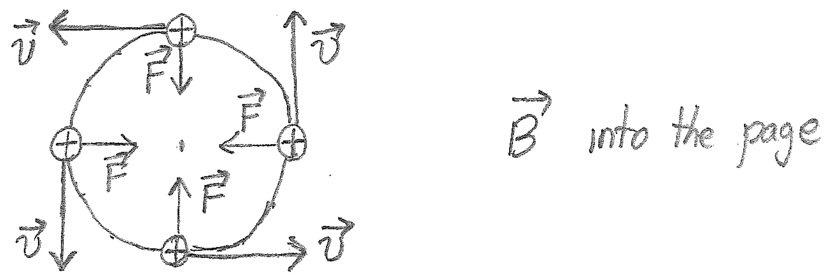
2. If $q > 0$, then $\vec{F}$ and $\vec{v} \times \vec{B}$ will point in the same direction.

3. If $q < 0$, then $\vec{F}$ and $\vec{v} \times \vec{B}$ will point in *opposite* directions. If $q < 0$ in the example above, the force will point *into* the page.

Charges moving in a uniform magnetic field in a plane perpendicular to that field will execute uniform circular motion if no other forces are present.[1] The force is perpendicular to the velocity (thanks to the cross product), and must point towards the center of that circle.

[1] It should be noted that if the initial velocity is not perpendicular to the magnetic field or the magnetic field is not uniform, then the charge will not execute circular motion, but will instead execute a more complicated motion. You will be discovering during the lab what happens to the motion if the velocity is not perpendicular to the field.

For example, consider a positive charge moving in the plane of the page with a uniform magnetic field pointing into the page.



You should verify the direction of $\vec{F}$ drawn in the picture above in each case, and try to answer the following:

1. What happens to the charge if $\vec{B}$ points out of the page instead of into the page?

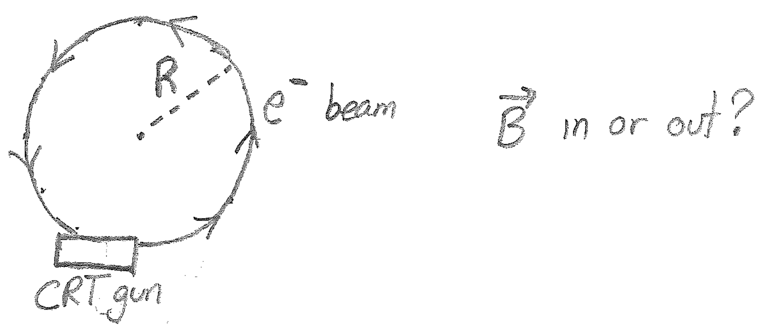
2. What happens if the charge is negative instead of positive?

In any case, if the charge is to execute circular motion, then the magnetic force (being the only force acting) must provide the centripetal force:

$$F_c = \frac{mv^2}{r} = |q|vB\,.$$

This provides a relationship between the mass, charge, magnetic field, speed, and radius of the circular path.

In the e/m lab, electrons are fired from a CRT (Cathode Ray Tube) gun into a region containing a (nearly) uniform magnetic field, which causes the electrons to execute circular motion, as shown below.



The magnetic field is created by passing current through Helmholz coils (not shown in the diagram above) and is perpendicular to the path that the electron follows (into the page or out of the page? — that is up to you to figure out). Before coming to lab, you need to work out a relationship between R, B, e, m_e, and the accelerating voltage V which gives the electrons their kinetic energy. In the e/m lab, you will measure the radius of the path for different values of the magnetic field (V will be measured with a voltmeter and fixed throughout the experiment), and use this data to calculate the charge to mass ratio (e/m) of the electron.